



## SECTION 5

### VARIABLES AFFECTING LEAK DETECTION METHODS

The capability of leak detection methods to accurately measure rates of leakage is affected by variables, as well as the detection method itself. The principal variables and the way they affect accuracy are discussed in this section. This discussion of variables precedes the description of leak detection methods in Section 6 to provide background information important to an understanding of the detection methods.

Principal variables which affect the accuracy of most of the available leak detection methods are:

- Temperature Change
- Water Table
- Tank Deformation
- Vapor Pockets
- Product Evaporation
- Piping Leaks
- Tank Geometry
- Wind
- Vibration
- Noise
- Equipment Accuracy
- Operator Error
- Type of Product
- Power Variation
- Instrumentation Limitation.
- Atmospheric Pressure
- Tank Inclination

The effects attributable to variables upon the ability to conduct leak detection tests for different detection methods are discussed in this section. The current methods used to compensate for the variables are discussed in Section 6 of this report.

### VOLUMETRIC LEAK DETECTION TESTS

Volumetric leak detection tests identify the leak or determine leak rate based on the measurement of properties associated with a change in volume. Certain variables affect the volume change or the measurement of the volume change.

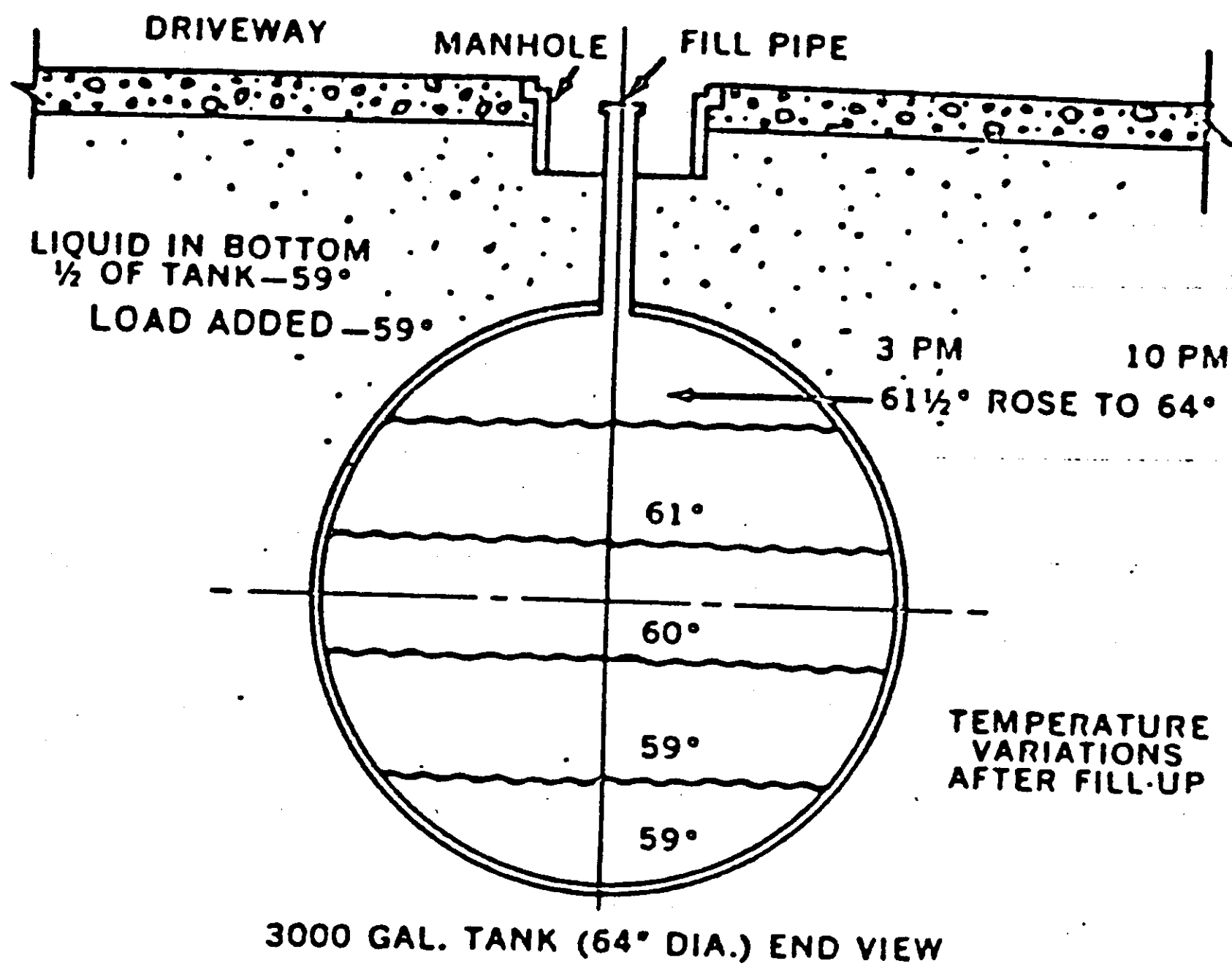


Figure 1. Temperature Stratification (4)

Ref: Heath Consultants, Inc. Petro Tite Tank Test Bulletin

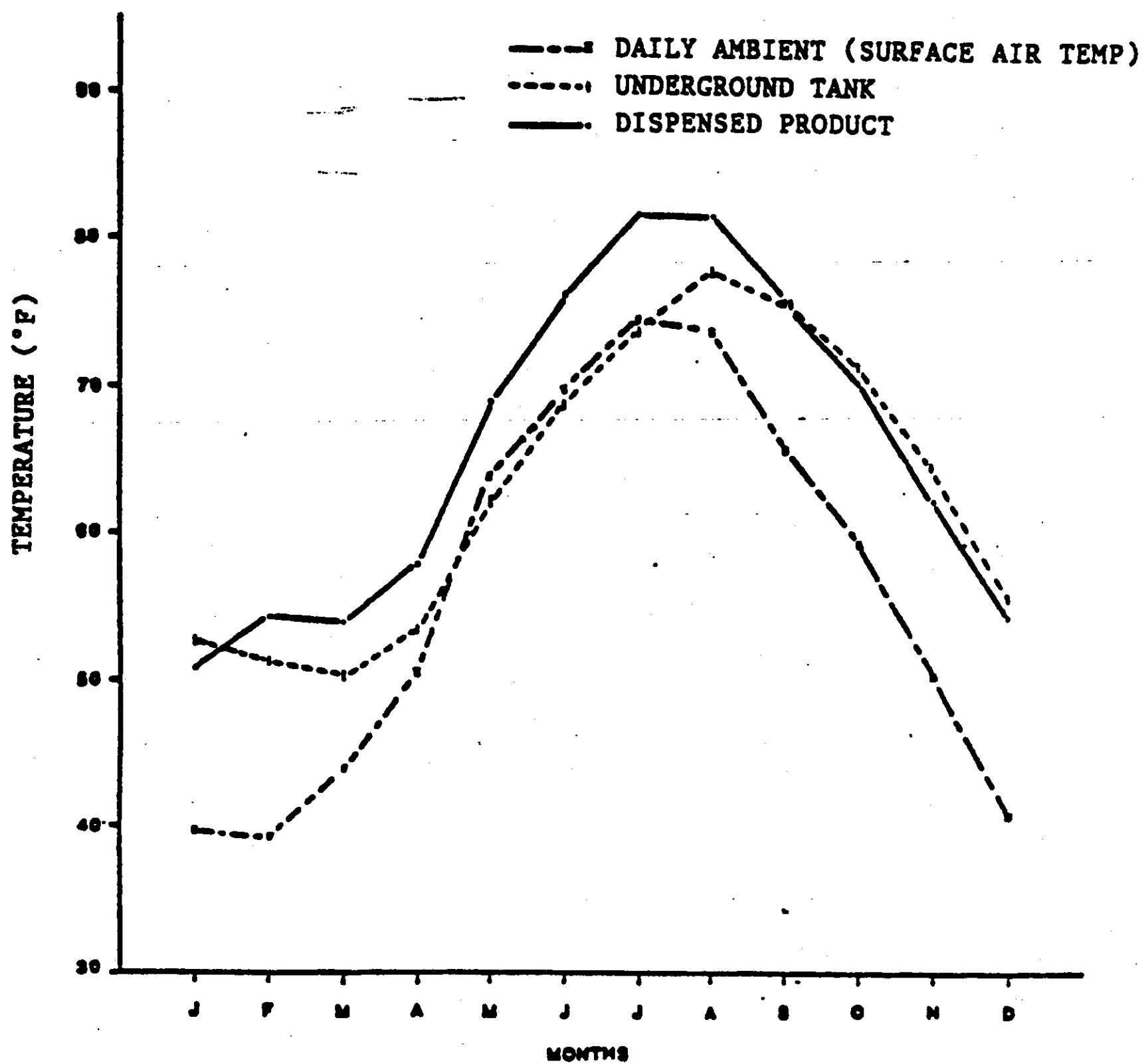


Figure 2. Average Gasoline Temperature For All Test Stations (5)

Ref: API Publication No. 4278

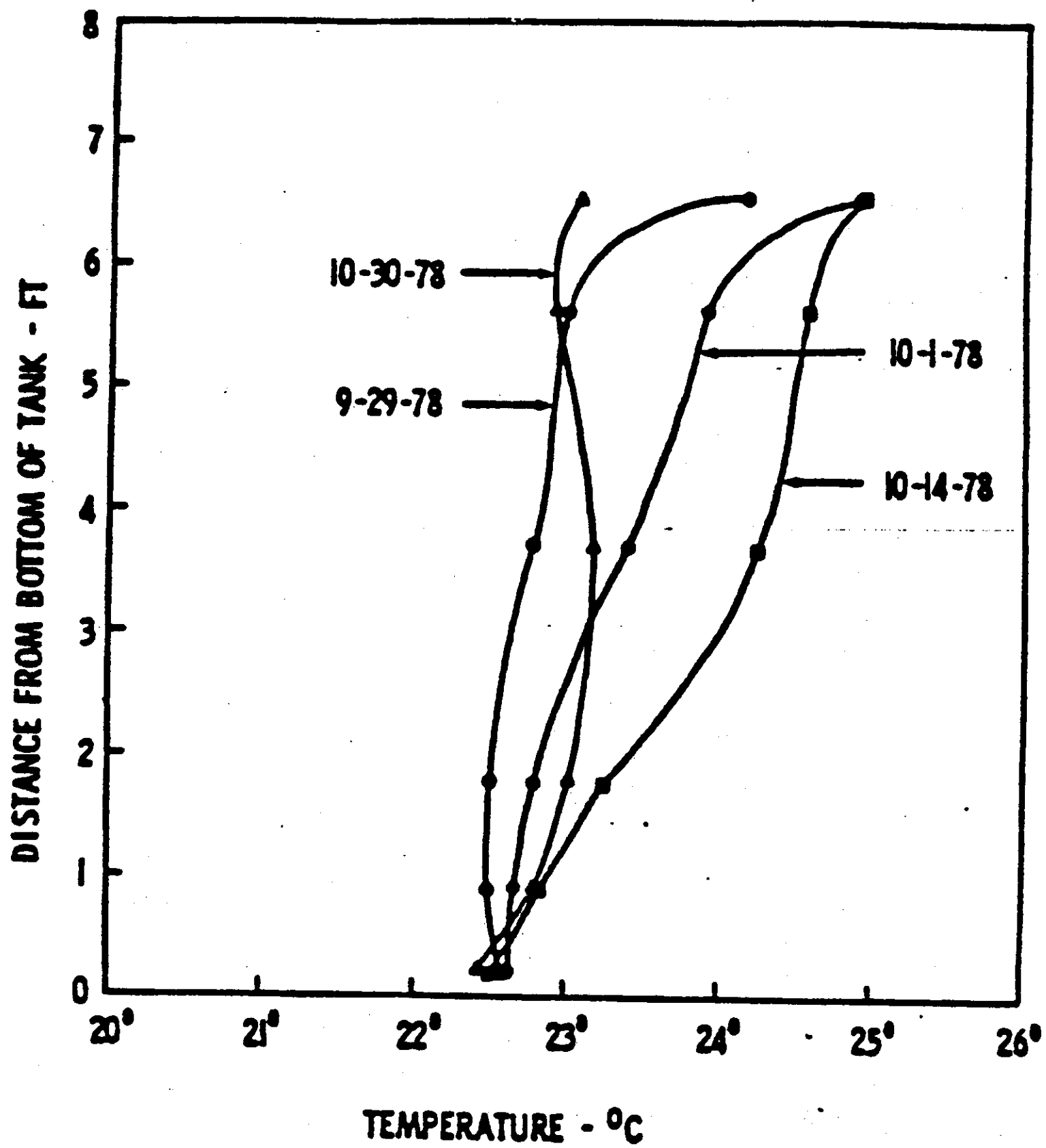


Figure 3. Mean Temperature Distribution As A Function Of Depth For Four Different 24-Hour Periods (5)

Ref: SRI International, Project 7637, Conducted for API  
Technical Report 1, June 1979

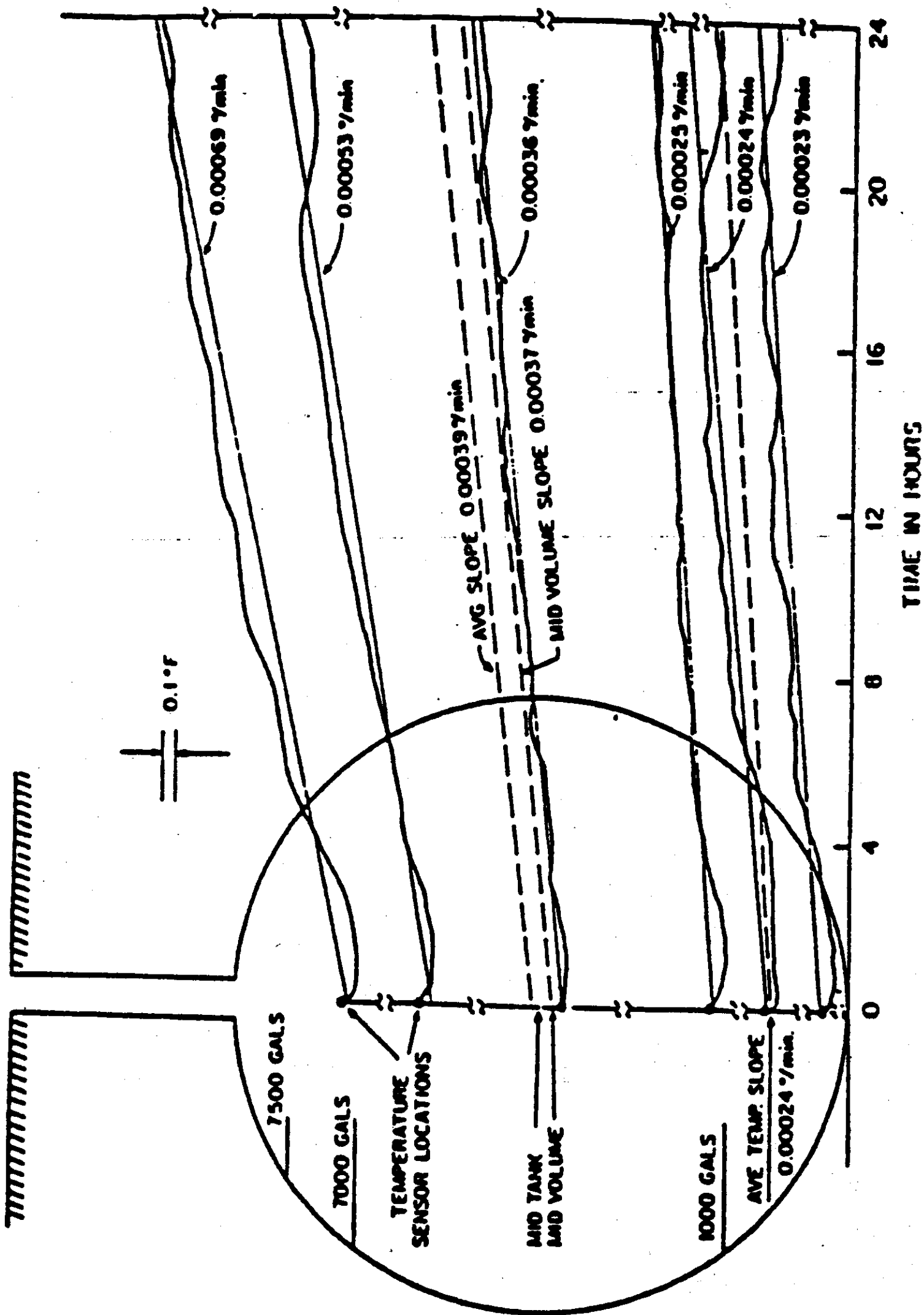


Figure 4. Tank Temperature Stratification And Gradients For A 24-Hour Period After Tank Fill Up (5)

Ref: SRI International, Project 7637, Conducted for API  
Technical Report, June 1979

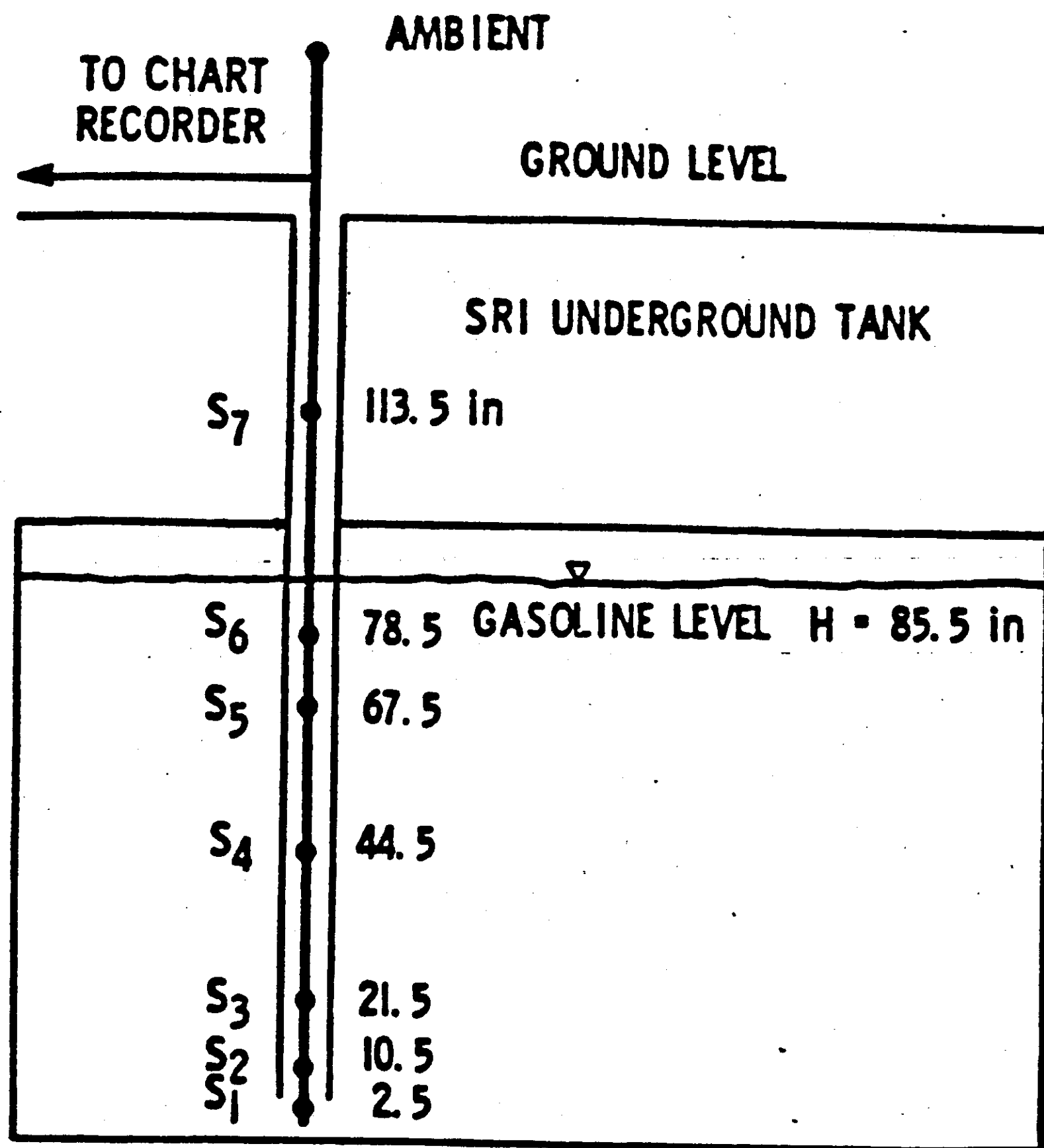


Figure 5. Location Of Temperature Sensors In The SRI Tank (5)

Ref: SRI International, Project 7637, Conducted for API  
 Technical Report 1, June 1979

## DELIVERY TEMPERATURES

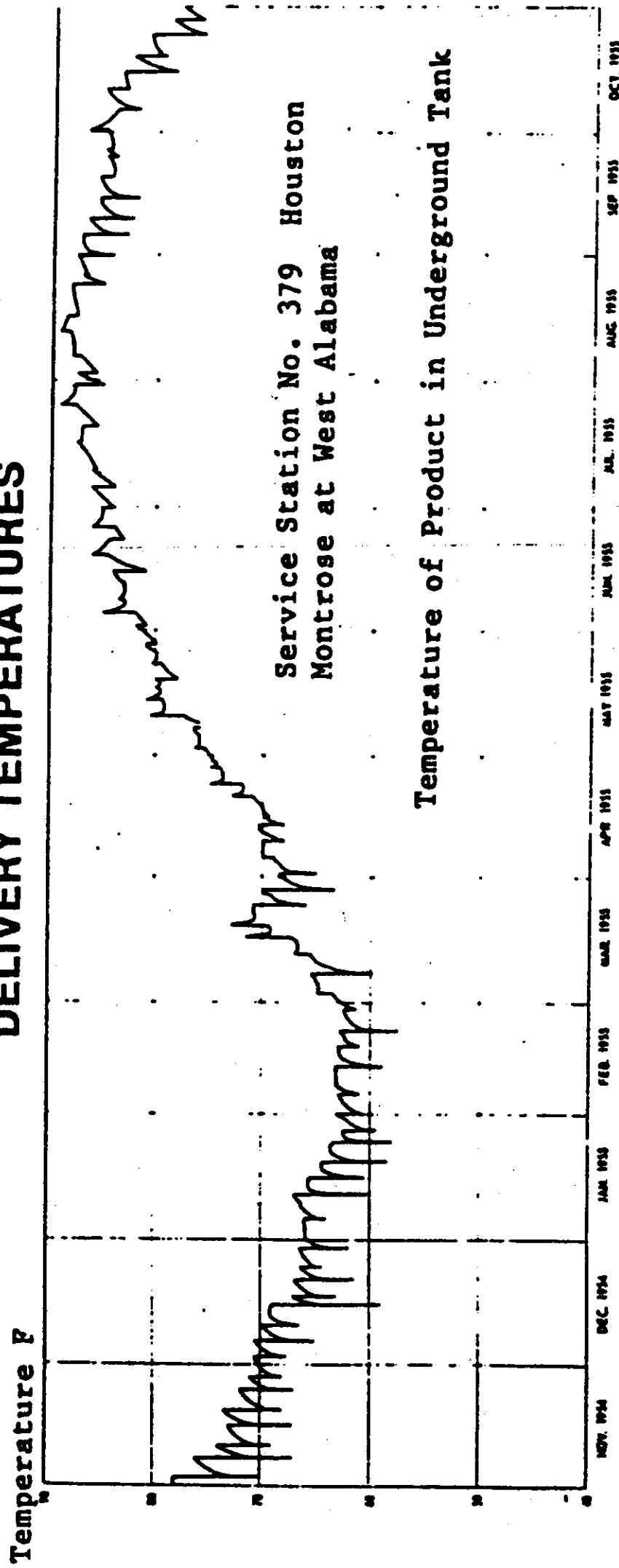


Figure 6. Delivery Temperatures

Ref: Heath Consultants, Inc., Petro Tite Tank Tester Bulletin

Figure 6 shows the graphed temperature recordings for an entire year by combining the results of 52 weekly graphs (4). The vertical lines, either down or up, show the immediate effect of the delivery on the tank temperature and the curving lines show the gradual return to underground temperatures.

The graph also shows a seasonal change of 30 degrees Fahrenheit in underground temperatures occurring even in south Texas. Much greater differences between summer and winter would exist further north and particularly in those areas of the country noted for hot summers and cold winters.

Ref: Heath Consultants, Inc., Petro Tite Tank Tester Bulletin



## Temperature

Changes in temperature cause expansion, or contraction, in the product and in tank dimensions. Due to the insignificant thermal coefficient of expansion for steel (fiberglass has a higher thermal expansion than steel) and existence of external factors (e.g., water table and fill material physical effects), the thermal variation of the tank cannot be measured during the occurrence of a leak and small temperature changes. The product volume change can be measured because it is much more sensitive to temperature change. When liquid is added to fill a tank for testing, several days may be required before the liquid stabilizes to ground temperature; however, ground temperature is also constantly changing (and thus prevents stabilization of the system's temperature). The rate of temperature change in the first day or two after addition of liquid will generally be in the range of 0.02 to 0.25 degrees Fahrenheit per hour (3). Temperature changes occur because of the following conditions (Figures 1 through 6) (4,5):

- Hot days
- Cool nights
- Sunshine
- Clouds
- Rain
- Water table
- Type and compaction of fill material.

Two important temperature effects should be considered: volume change and stratification. Gasoline has an expansion coefficient of 0.00068 gallons per degree Fahrenheit (Table 10) (4). To detect leaks as small as 0.05 gallons per hour, a change of 0.01 degrees Fahrenheit per hour in a 10,000-gallon tank may cause a 0.068-gallon change in the product volume per hour, thus offsetting or amplifying an observed leak rate. This temperature effect could be eliminated by accurate temperature measurement. However, the stratification normally present in underground tanks should also be considered. Stratification is due to the variation of product temperature from the top to the bottom of the tank. The top layer temperature may be several degrees higher than the bottom layer. The layer temperatures usually change at different rates at different levels, which makes the temperature measurement more complicated.

## Water Table

Hydrostatic head and surface tension forces caused by ground water outside an underground storage tank may mask tank leaks partially or completely. Such leaks may take the form either of product leaving the tank or of ground water entering. When the forces are equal at two sides of a leak opening before or during the testing period, a complete masking effect occurs. The chance of this situation occurring increases

TABLE 10. THERMAL EXPANSION OF LIQUIDS (4)

Ref: Heath Consultants, Inc., Petro Tite Tank Tester Bulletin

TYPE OF PRODUCT	VOLUMETRIC COEFFICIENT OF EXPANSION PER DEGREE F
Benzol (benzene)	0.00071
Diesel fuel	0.00045
Ethyl alcohol	0.00062
Fuel oil #1	0.00049
Fuel oil #2	0.00046
Fuel oil #3	0.0004
Gasohol	
0.10 Ethyl + 0.90 Gasoline	0.000674
0.10 Methyl + 0.90 Gasoline	0.000684
Gasoline	0.00068
Hexane	0.00072
Jet fuel (FP 4)	0.00056
Kerosene	0.00049
Methyl alcohol	0.00072
Stove oil	0.00049
Tuluol (toluene)	0.00063
Water at 68°F	0.000115

These are average values and may vary. If there is any doubt, the product should be checked with a hydrometer.

when the testing method is performed on a tank which is not completely filled and especially when no product is added or removed for testing. The level of ground water may vary seasonally or because of intensity and duration of rainfall. To evaluate the masking effect, the relationship between the product level inside the tank and the ground water level outside the tank system must be known.

### Tank Deformation

Changes or distortions of the tank due to significant changes in pressure or temperature can cause an apparent volume change in the product. This is called the tank deformation effect (Figures 7 and 8) and may be affected by the wetness and nonhomogeneous properties of backfill material around the tank (4), the material of tank construction, the thickness of the tank shell, the age of the tank, and forces due to ground water level exerted on the tank. The tank deformation effect is uncontrollable and different for every tank.

The construction of steel tanks is such that distortion effects of the flat ends are generally much greater than that of the cylindrical sides (the reverse is generally true for fiberglass tanks). The pressure within a tank will vary with the specific gravity of the liquid and the liquid height above the bottom of the tank. These pressures can be computed for any height of the tank from Table 11 (4). The total change of the force, in tons, at various pressure changes on each end of a typical steel tank is shown in Table 12 (4).

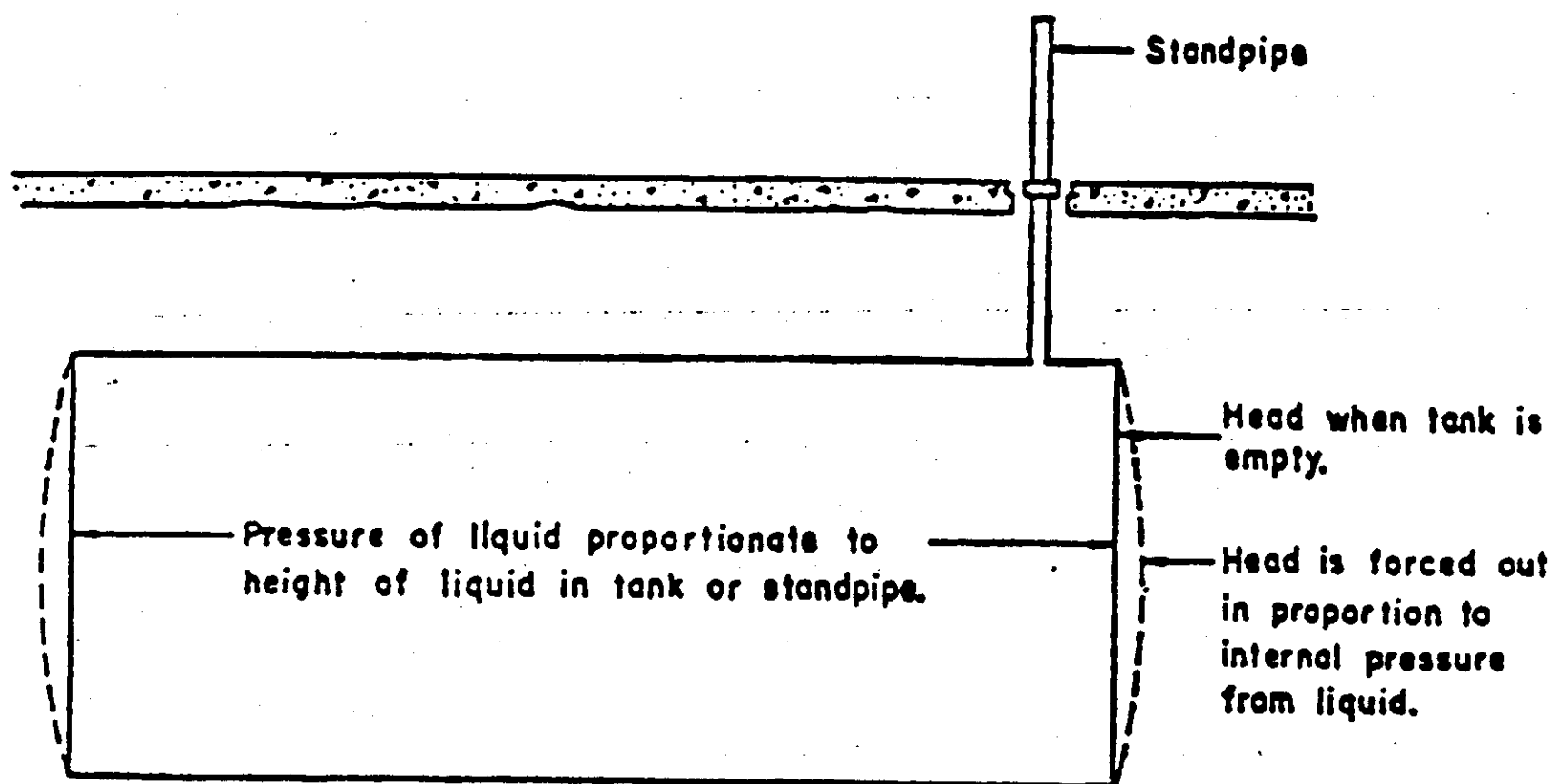
In some methods for testing tanks with large diameters, the stabilization time for tank end deflection may be more than 36 hours. The stabilization time for deflection of an underground tank is important because the apparent product volume loss caused by tank end deflection cannot be measured and may mask the occurrence of a leak. For example, in a 96-inch-diameter steel tank, the apparent loss of product volume is 1.957 gallons for 1/16-inch tank end deflection. If this volume change occurs within one hour and if it occurs during the test period, it will offset the testing accuracy and the tank will appear to be leaking. The magnitude of apparent volume change for various deflections of a given size steel tank, when it is filled, can be found in Table 13 (4), Figure 8 (5), or can be calculated from the following formula (4):

$$V_T = \left[ \frac{\pi}{2} \left( r^2 + \frac{h^2}{3} \right) h \right] [2]$$

where  $V_T$  = total volume change due to tank end deflections, in.<sup>3</sup>,

$r$  = tank radius, in., and

$h$  = deflection of tank end, in.



**Figure 7. Tank End Deflection (4)**

**Ref: Heath Consultants, Inc. Petro Tite Tank Tester Bulletin**

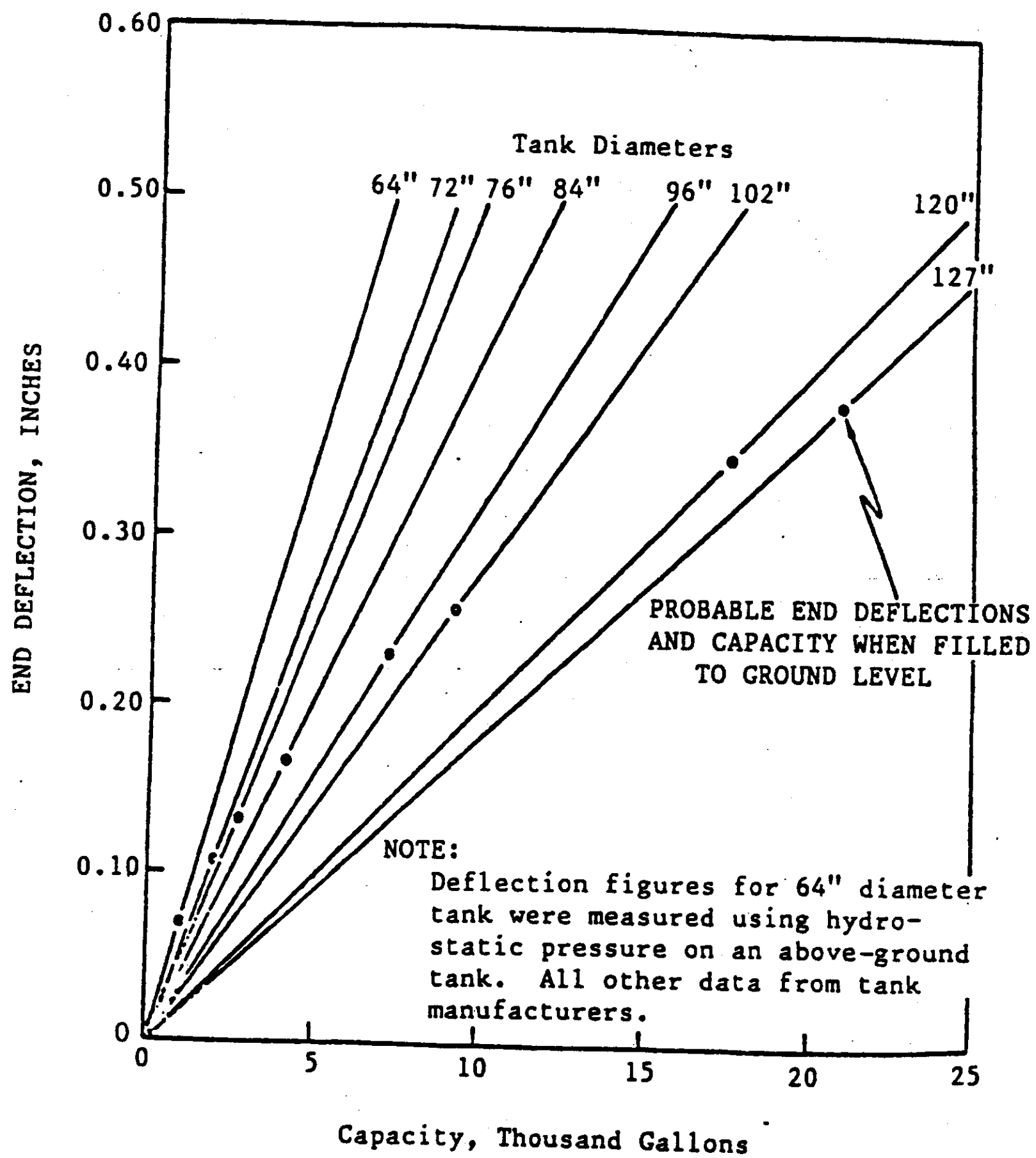


Figure 8. Change in Tank Volume Due To Tank End Deflections - In Gallons (5)

Ref: Hunter Environmental Services, Inc., Leak Lokator LD2000

TABLE 11. PRESSURE-HEIGHT CHART (4), LBS/SQ. IN.

Ref: Heath Consultants, Inc., Petro Tite Tank Tester Bulletin

PRESSURE - HEIGHT CHART				
Height	Gasoline	Kerosene	Fuel Oil	Water
1 In.	.026	.029	.031	.036
2 In.	.053	.058	.061	.072
3 In.	.079	.088	.092	.108
4 In.	.105	.117	.123	.144
5 In.	.132	.146	.153	.181
6 In.	.158	.175	.184	.217
7 In.	.188	.209	.219	.258
8 In.	.211	.234	.245	.289
9 In.	.237	.263	.276	.325
10 In.	.264	.292	.307	.361
11 In.	.290	.322	.338	.397
1 Ft.	.316	.351	.368	.433
2 Ft.	.632	.702	.736	.866
3 Ft.	.949	1.053	1.105	1.300
4 Ft.	1.265	1.404	1.473	1.733
5 Ft.	1.581	1.754	1.841	2.166
10 Ft.	3.162	3.509	3.682	4.332
15 Ft.	4.744	5.263	5.523	6.498
	Specific Gravity		API Gravity	
Water	1.00	at 62° F.	Typical	
Gasoline	.73		62.3) gravity	
Kerosene	.81		43.2) readings	
Fuel Oil	.85		35.0) vary with grade and season.	

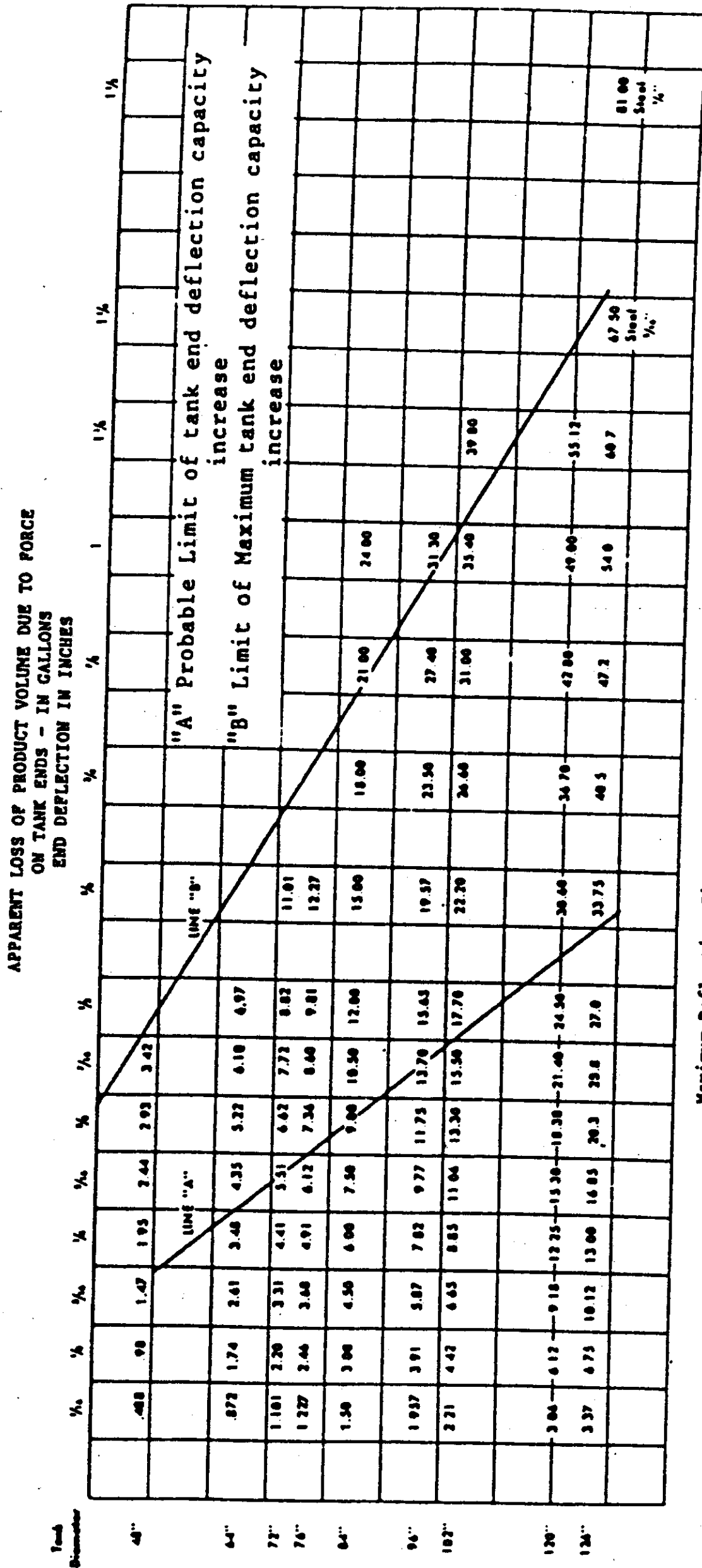
TABLE 12. TOTAL FORCE ON TANK ENDS (4)  
 FORMULA: FORCE = (AREA) X (PRESSURE) (LBS/SQ. IN.)  
 TOTAL FORCE IN TONS AT:

Ref: Heath Consultants Inc., Petro Tite Tank Tester Bulletin

Tank Dia.	1 Psi.	2 Psi.	3 Psi.	4 Psi.	5 Psi.
48"	0.9	1.8	2.7	3.6	4.5
64"	1.6	3.2	4.8	6.4	8.0
72"	2.0	4.0	6.0	8.0	10.0
84"	2.8	5.6	8.4	11.2	14.0
96"	3.6	7.2	10.8	14.4	18.0

TABLE 13. APPARENT LOSS OF PRODUCT VOLUME (4)  
DUE TO FORCE ON TANK ENDS - IN GALLONS

Ref: Heath Consultants, Inc., Petro Tite Tank Tester Bulletin



Maximum Deflection Figures are Preliminary based on limited data  
from Tank Manufacturers and completely fluid soil conditions  
Measurements were made with air pressure above ground

## Vapor Pockets

Vapor pocket effects may offset the test results obtained via methods which require the tank to be overfilled. This effect increases when rapid changes in ambient pressure or temperature occur during the test period. Basically, three types of vapor pockets are possible: one that forms in the high end of a tank when the tank is not perfectly level, one that is trapped in the top of the manway, and one that is trapped at the top of a drop line (Figure 9) (5). The vapor pocket may release due to a pressure decrease or temperature increase and lead to inaccurate leak test results. Even if the vapor pocket is not released during the test, a change in its temperature or pressure will cause a change in its volume, thus leading to an inaccurate test result. Therefore, vapor pockets should be minimized, without excavations, if feasible. Within a short period of time, vapor pockets trapped in abandoned lines will possibly have a significant effect, especially if vapor pockets are close to grade and are subjected to ambient temperature change. As an example, for a two-cubic-foot vapor pocket at 60 degrees Fahrenheit, a 2.5 degrees Fahrenheit temperature decrease will cause a volume decrease of 0.05 gallons.

## Product Evaporation

Evaporation causes a decrease in volume which, if not accounted for, would be interpreted as a leak by the leak measurement device. Awareness of this effect is particularly important in hot weather, dry climates, and high altitudes. The evaporation rate may differ, depending on whether the volume change of the product is measured in or under the fill pipe. The evaporation rate also depends on the volume of the empty space in the tank above the product level. The presence of more empty space above the product level will provide more volume for gasoline evaporation before the space is saturated. For example, in a dry climate at 70 degrees Fahrenheit ambient temperature, for a four-inch fill pipe filled with gasoline, a rate of 0.014 gallons per hour gasoline evaporation can be calculated by Fick's Law of mass transfer. This is equivalent to an 0.3 inches per hour reduction of the gasoline level in the fill pipe.

## Piping Leaks

Leaks at tank vents, manholes, or other piping connections to the tank will cause misleading results during the leak detection tests (because in some leak testing methods, this type of leak cannot be differentiated from leaks which occur in the tank).

## Tank Geometry

Many of the volumetric leak detection methods are product-level and/or temperature-sensitive. In either case, one or more tank specifications (e.g., the product surface area at different elevations



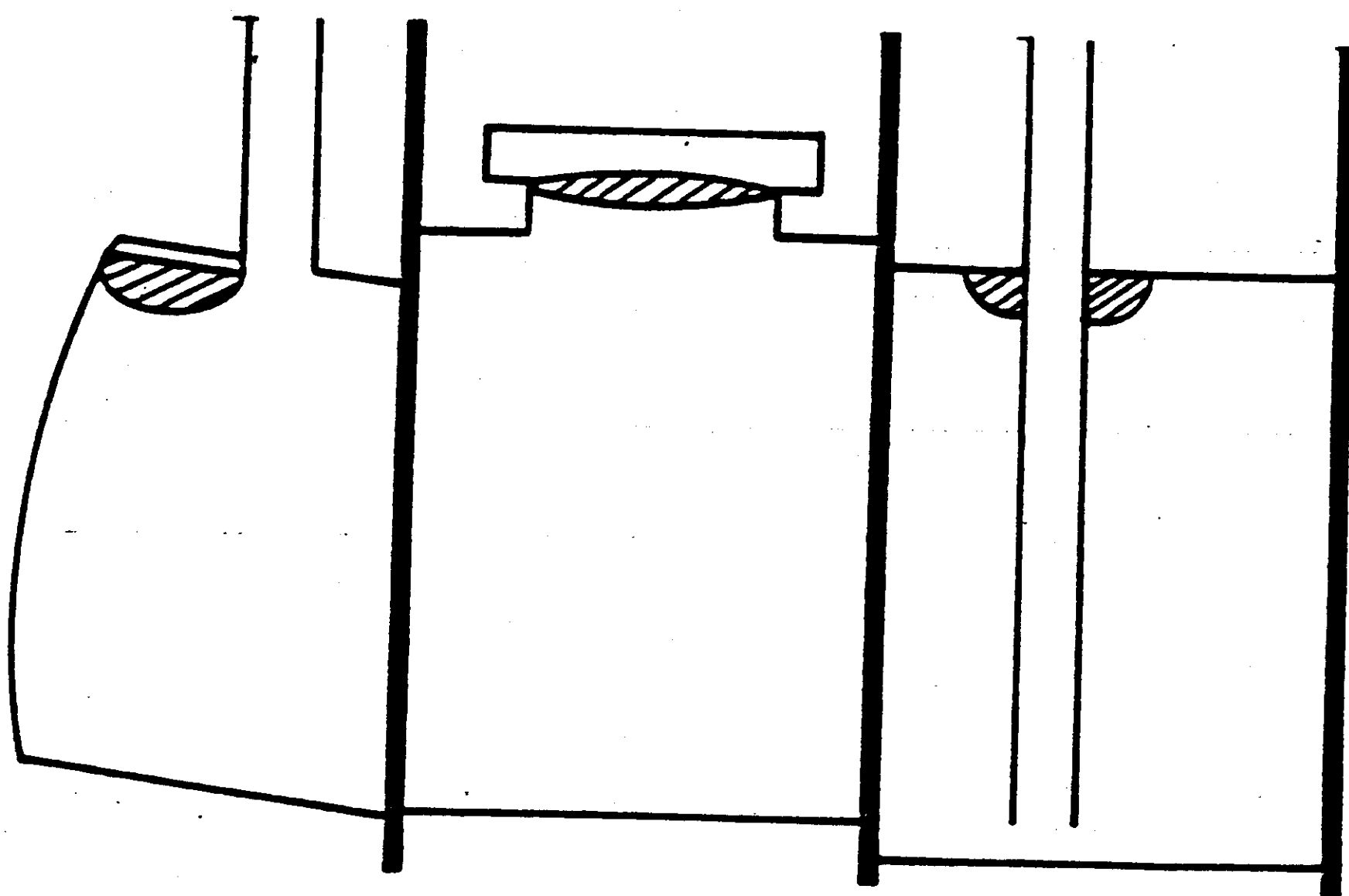


Figure 9. Examples Of Three Common Vapor Pockets (5)  
Ref: Hunter Environmental Services, Inc., Leak Lokator LD2000

of the tank or the volume of the tank) is used to calculate the overall volume change and the total volume change due to the temperature change during a test period. In either case, differences between the actual tank specification and the nominal manufacturer's specification can affect the accuracy of test result evaluations.

When a reference tube filled with product is used to measure the representative level changes due to temperature variation, the cylindrical geometry of the tank affects the accuracy of the test results. This effect is minimized when the product level is at 75 percent of a tank diameter, and increased at higher product level (33).

#### Wind

When a leak detection method is sensitive to product level or pressure changes and the fill pipe or the vents are kept open to the atmosphere during testing, the test results can be affected by wind. Wind, especially when it is strong, can disturb the testing and reduce the data reading accuracy by creating a wave on the product free surface, irregular fluctuation of the pressure exerted on the liquid, or both. The effect is more pronounced when the product level is below the fill pipe.

#### Vibration

In some leak detection methods, external influences such as ground vibration, traffic, wind, and background noise may cause inaccurate test results. The vibration effect decreases when the testing results are recorded based on a continuous average detection; this can be provided by using a microprocessor. The vibration effect in level measurement increases as the free surface area of the product increases when the test is conducted at product level under the fill pipe. The magnitude of the vibration effect is very difficult to measure precisely. When the test method is based on the product level measurement in the fill pipe, the vibration may be enough to change the overall result from "not leaking" to "leaking" (from slightly below 0.05 gallons per hour to slightly above).

#### Noise

Noise can affect the testing accuracy of a product level- or sound-sensitive detection method. None of the volumetric leak detection methods are sound-sensitive. In product level-sensitive detection methods, the vibration due to powerful noise such as an explosion or thunderstorm or nearby reciprocating machinery can create waves and reduce the accuracy of the product level measurement. Typical background noise has insignificant effect on the accuracy of nonsound-sensitive detection methods.

## Equipment Accuracy

Because changes of variables during a test period are commonly measured, the equipment accuracies reported by most of the manufacturers are the sensitivity of the equipment to respond to certain variation. However, the equipment accuracy (the ratio, multiplied by 100 percent, of error in measurement to actual value) is subject to change at different operating conditions such as temperature, pressure, range of the measurement, etc. If the variations are not compensated for during testing, they can reduce or change the accuracy of the detection method.

## Operator Error

The more complicated the testing procedure, the greater the potential for operator error. Typically, this is minimized or reduced by using trained and experienced operators to conduct the testing. In some cases, when the testing requires extensive sealing of the system's ports and openings, improper sealing also could be considered as operator error.

## Type of Product

The physical properties of the product (including effects of possible contaminants) could affect the repeatability and/or applicability of a detection method. However, in all the identified leak detection methods in this report, the accuracies are reported to be unaffected by the type of product with physical properties similar to gasoline. These include jet fuel, diesel fuel, and kerosene.

## Power Variation

Most of the detection methods require electric power for operation. In some methods, this power is provided by using batteries. Usually, the batteries are replaced with new ones before each testing. This reduces the testing inaccuracy due to power variation. However, when a method uses a 110V AC electric source, the results can be affected by power variations during a test period. This effect can be reduced when both the test results and voltage measurements are printed against a common time base and considered together during the final interpretation.

## Instrumentation Limitation

Some of the leak detection methods are applicable to be used and operated under certain tank situations or operating conditions. This can be due to the size and range of applicability of the instruments used in a method. Size of a fill pipe, inclination of the fill pipe, range of product level or pressure change are examples of variables which can limit the applicability of a method. If an attempt is made to use a method outside of its designed range, the accuracy of detection will be decreased.

## Atmospheric Pressure

Barometric pressure change during a test period can affect leak rate measurement. For example, in a 10,000-gallon tank filled with gasoline at approximately 60 degrees Fahrenheit (assume constant compressibility factor) with a vapor pocket size of four gallons, a pressure change of 0.02 inches of mercury provides an approximate apparent leak equal to 0.0035 gallons. However, about 80 percent of this volume change is due to the presence of the vapor pocket (because of the difference between the compressibilities of air and gasoline). An apparent leak of approximately 0.01 gallons would result from a change in barometric pressure of 0.07 inches of mercury.

## Tank Inclination

When a product level-sensitive detection method is used to determine leaks in an underground storage tank, tank inclination can affect detection accuracy. In an inclined tank, the volume change per unit of level change is different than in a horizontal tank. This is due to the difference between cross sectional areas, at certain product elevations, for inclined and vertical conditions. This effect is corrected by measurement of level change due to a known product volume change.

In some cases, significant inclination may cause the method to be inapplicable.

## NONVOLUMETRIC LEAK TESTS

The nonvolumetric leak detection test is used to determine the presence of leaks by qualitative analysis, usually by using a second material other than the product (tracer material). The performance of testing may be affected by certain variables.

## Temperature

If a tank must be emptied and then filled with a tracer material (usually helium) prior to leak testing, the temperature effect can change the pressure and the viscosity of the tracer material. The leak rate of tracer material will increase with temperature increase. This is the result of pressure increase and viscosity decrease of a tracer material due to temperature increase, both of which tend to increase the leak rate. However, because the typical tracer material is helium with significant diffusivity, the temperature increase can only reduce the detection time of the tracer slightly. Therefore, the accuracy of this test is not significantly affected by temperature changes.

Some detection methods, in addition to detection of leaks by tracer gas, attempt to provide an approximate leak rate by pressure monitoring

during a test period. These methods must compensate for pressure change due to temperature effect.

If testing is conducted with product at normal existing conditions and leaks are detected by monitoring the sound due to leaks or detection of tracer gas outside a tank, the change of the leak rates due to temperature change will have slight effect on the detection time and no effect on the testing accuracy.

The change of the temperature would be based on ambient temperature change, sunshine, clouds, rain, water table, and type and compaction of backfill material.

### Water Table

If a detection method indicates a leak by detection of tracer gas outside of a tank, the presence of a high water table can prevent the exit of the tracer gas from the tank. However, this can be overcome by increasing the pressure of the tracer material inside the tank until it exceeds the external pressure, in which case the tracer gas (helium) will bubble up through the water to the surface. For certain pressure of tracer material inside the tank, a higher water table will result in a longer detection period.

Some detection methods, in addition to the detection of leaks by sniffing tracer gas outside a tank, attempt to provide maximum possible product leak rate by pressure monitoring inside the tank. In this case, a partial masking effect of the water table affects the testing accuracy for leak rate evaluation.

When a method is applied to detect leaks by sound monitoring of the leak under pressurized or vacuumed tank conditions, a lower partial masking effect (lower water tables) can cause a more pronounced sound for detection of a leak. In this case, due to the pressure differential at two sides of a leak opening, a complete masking effect is avoided.

### Tank Deformation

The nonvolumetric methods operate either by monitoring a tracer gas outside a tank or monitoring the sound due to a leak inside a tank. Therefore, tank deformation does not affect the detection accuracy. (However, the effect of the tank deformation on the diameter of small-size leaks should be studied.)

When a method provides the maximum possible leak rate of the product by pressure monitoring inside a tank, the tank end deflection effect on the leak rate will decrease for longer test periods.

### Vapor Pocket

In nonvolumetric detection methods it is necessary to test a tank at emptied or normal existing product level condition. Therefore, during these testings, vapor pockets cannot be created.

### Product Evaporation

When testing is conducted on a completely empty tank, the product evaporation effect is eliminated. If a nonvolumetric method indicates leaks by detection of a tracer gas outside a tank or sound monitoring of leaks inside a tank, in both cases at normal existing product level, the product evaporation cannot affect testing performance.

### Piping Leaks

In nonvolumetric tank leak testing with tracer gas, leaks at tank vents, manholes, or other piping connections to the tank can cause misleading results. This is because the tracer gas is very diffusive and can diffuse through some pipe connections even after they are tightened enough to contain liquids.

### Tank Geometry

None of the nonvolumetric leak detection methods is product level-sensitive. Therefore, tank geometry does not affect testing.

### Wind

Based on the testing procedures for nonvolumetric detection methods, all the ports of a tank should be sealed from the atmosphere prior to testing to assure that the wind does not affect the testing performance. However, in some detection methods where leak detection is performed by sniffing a tracer gas at the ground level above a tank, in windy conditions, small monitoring holes should be installed. This will prevent the masking effect of wind for detection of tracer gas by direct sniffing of gas through monitoring holes.

### Vibration

None of the nonvolumetric detection methods are sensitive to the level change of any fluid during a testing period. Therefore, the testing performance is not affected by the vibration effect.

### Noise

Noise can affect the testing accuracy of a sound-sensitive detection method. Unless the background noise can be differentiated from the sound due to leaks, the test cannot be successfully carried out.

## Equipment Accuracy

(See the description for volumetric leak detection methods.)

## Operator Error

In all nonvolumetric methods, all tank ports must be sealed from the atmosphere. Therefore, one of the major potentials for operator error is the operator's ability to seal a tank completely prior to a test. In sound-sensitive detection methods, the operator's level of experience can reduce the time required to assure the certainty of detecting leaks or the leak rate.

## Type of Product

When testing is performed in an empty tank, the effect due to type of the product will be completely eliminated. In acoustical leak detection methods which are conducted in tanks containing product, the product viscosity can affect the sound characteristics of leaks below the product level. However, for products with properties similar to liquid petroleum fuel, this effect is insignificant.

## Power Variation

The nonvolumetric leak detection methods are based either on detection of a tracer gas (helium) outside the tank or detection of the leak sound inside a tank. In either case, the typical AC power variation during the detection period cannot be enough to mask the detection completely.

## Instrumentation Limitation

(See the description for volumetric leak detection methods.)

## Atmospheric Pressure

Because all the nonvolumetric detection methods are operated only after the tank ports are sealed to the atmosphere, atmospheric pressure (barometric pressure) change has no effect on the test results.

## Tank Inclination

Because none of the nonvolumetric leak detection methods are product-level sensitive, tank inclination does not affect testing.

## General Problems

The principal problems inherent in nonvolumetric detection methods are that they:

- Cause or enhance a leak during testing by exerting pressure higher than normal tank operating pressure.
- Adversely affect product quality if a compound that is not inert is used for testing in a tank containing product.
- Risk an explosion hazard when product is present in the tank during testing.
- Usually cannot measure leak rate accurately, or at all.
- Require a long testing time for low leak rates when the type and compaction of the backfill material around the storage tank is varied. In some cases, the testing time could be up to 24 hours.

### INVENTORY CONTROL

The problem of keeping records of product inventory is complicated by the fact that gasoline is volatile and losses due to evaporation are, to a degree, unavoidable. However, the inventory method could be used as a first and most convenient method for gross leak monitoring. The accuracy of this method is very much related to the manner in which variable factors are compensated.

### LEAK EFFECTS MONITORING

Problems associated with methods in this category are not discussed in this section because these methods are not considered as existing or developing in-tank, leak detection techniques, which are the focus of the present study.